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Frequently Asked Questions Regarding Biological Detection

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November 2001

IDA Document D-2663
Log: H 01-002013

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PREFACE

This study was performed for the Independent Research Program. The author would like to thank Ms. Eileen Doherty for editing this paper. Any inaccuracies or errors are the sole responsibility of the author.

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SUMMARY

A biological agent attack is the release of an aerosol of disease-causing organisms or biologically-derived materials into the atmosphere. Detecting such a release requires sophisticated technologies fashioned into operationally useful equipment. It is therefore critical for military operators and technologists to be able to communicate with each other in order to translate operational requirements into technical specification, on the one hand, and technical performance into operational capabilities on the other. Through a question and answer format, this paper attempts to lay out some of the intricacies of biological detection, in the hopes that better information flow between the operator and the technical communities will result in improved biological defense.

FREQUENTLY ASKED QUESTIONS ON BIOLOGICAL AGENT DETECTION

Introduction

Over the years, IDA has supported a number of studies dealing with biological weapon agent detectors. Among the detectors analyzed are the BIDS, the LRBSDS, Portal Shield, the CP-Lidar, the JBREWS, the JBPDS, and the JBSDS. Although many of these analyses have been documented in IDA papers, these papers are not widely available and many analyses have been summarized only in briefing form, to support ACTDs and other time-sensitive activities.

During the course of these analyses, we found that educating analysts, operators, and decision makers in the intricacies of biological detection was a challenging endeavor. Not only is there a great deal of scientific and technology detail involved in the generation and movement of biological agent aerosols in the atmosphere and the mechanisms by which those aerosols are detected by the various detectors, but there is also considerable scope in what is done operationally once the detectors (or system of detectors) have made a determination that there is agent in the air. Actions can range from taking protective measures such as donning protective masks, to implementing medical treatments, to calling up replacement forces to carry on the missions of personnel who have been exposed and who will inevitably become casualties because there is no treatment available that will allow the exposed personnel to continue to function.

Although there are a number of technologies that are candidates for biological agent detectors, many issues are independent of the technologies used. These issues should be understood by everyone who wants to comprehend how to set requirements for biological sensors, how to deploy and use them, and what to expect in terms of their contributions to the warfight. Accordingly, we decided to condense what we had learned from our studies and analyses and summarize these findings in an unclassified format.

WHAT IS A BIOLOGICAL AGENT ATTACK?

Almost all known biological agents are respiratory hazards. They are weaponized so that they will be released as particle aerosols in the air. These particles comprise either infective agents, such as viruses or bacteria, or disease-causing toxins, which are essentially chemicals. The particles move with the winds. If personnel breathe these aerosols, and enough particles are retained in the respiratory tract, the personnel become sick or die. The wind-borne nature of the biological aerosol is a defining characteristic.

How the winds move over terrain and around obstacles determines which people will be exposed to biological agent, and winds can move in unpredictable and complex patterns.

HOW DOES A BIOLOGICAL AGENT ATTACK DIFFER FROM A CHEMICAL AGENT ATTACK?

There are a number of similarities between biological and chemical attacks, but also a number of important differences. Both types of agent can be weaponized in similar manners and both are released as particle or liquid aerosols. Chemical agents, particularly persistent ones, can rain out onto surfaces, leaving hazardous residue. Biological agents generally remain aerosolized and do not leave contaminated areas, except in rare cases near a release point where high concentrations of agents might be found. Chemical agents are not only inhalation hazards, like biological agents, but also can be percutaneous hazards, so that vapor or liquid coming into contact with bare skin can cause adverse reactions. Biological agents do not pose a percutaneous agents. Biological agents that have settled on the ground are also not a hazard unless they are re-aerosolized in sufficient concentrations so as to be hazardous.

In general, the effects of biological agents are not seen for some time. Disease does not appear for several days, although, for some toxins, symptoms might present in several hours. Once symptoms do appear, however, it is often much more difficult, or impossible, to treat the disease. Chemical agents tend to elicit a very quick reaction, and, except for massive doses, effects can be reversed with chemoprophylaxis, at least for nerve agents.

Finally, biological agents tend to be more effective on a comparable weight basis. While substantial amounts of chemical agents are needed to cause significant numbers of casualties, very small amounts of biological agent can cover broad areas, if disseminated efficiently.

Thus, the key differences between biological and chemical attacks are: biological attacks require much less agent; biological attacks constitute a respiratory hazard only; there is generally no lasting contamination left by biological attacks; and the effects of biological attacks may not be seen for days.

HOW CAN FORCES BE PROTECTED AGAINST BIOLOGICAL ATTACK?

There are a number of ways that forces can be protected against biological agents. First, there may be medical measures that can be taken before or after exposure to counter the diseases caused by biological agents. Vaccinations, antibiotics, and antiviral agents

can prevent or ameliorate the effects of some agents. For some agents, however, these measures are ineffective. Since biological agents are delivered as aerosols that pose respiratory hazards, respiratory protection works well to prevent exposure, if used at the appropriate time. Although current doctrine for US forces is to assume MOPP4 protection during biological attacks, it is only the mask that is necessary. Military style protective masks are not necessary—any masks that filter out particles in the appropriate size-range work just as well. They need to be worn the entire time that the biological aerosol cloud is present.

WHAT IS THE PARTICLE SIZE-RANGE FOR BIOLOGICAL AGENTS?

The conventional wisdom is that biological agent particles should be in the one to ten-micron range to maximize retention in the respiratory system. While these sizes are, in fact, retained effectively within the respiratory passages, other sizes should not be ruled out. Larger sizes have been used by foreign biological weapon programs and for delivery of medicines and smaller, submicron particles; they can also be retained in the respiratory passages. Hence, larger or smaller particles might need to be considered both in developing protective measures, and in designing detectors.

WHAT IS THE ROLE OF BIOLOGICAL DETECTORS?

Because the only defensive approach that is effective against all biological agents is preventing exposure, one must know when a biological attack has occurred. The role of biological detectors is primarily to sense that there is biological agent in the vicinity. Other sensors and information sources might provide information that an attack that *could* be biological has occurred—such as a missile landing nearby—but only a biological detector can distinguish such an attack from conventional or chemical attacks. In addition to their role as a warning device, biological detectors perform a number of other functions (not all detectors perform all functions):

- Some biological detectors can take samples of the agent for later analysis or for forensic purposes—to provide proof that an attack has occurred.
- Some biological detectors can perform tests that will identify the biological agent, providing guidance to commanders and medical personnel regarding what the effects of the agent might be and what medical actions might need to be taken.
- Some biological detectors, either by themselves or when combined into systems, provide indications of the extent of the hazard (limited by their sensitivity, see below).

- Some biological detectors can estimate the concentration of agent, which assists in determining the extent to which personnel are at risk.

WHAT IS THE DIFFERENCE BETWEEN "DETECT TO WARN" AND "DETECT TO TREAT?"

These terms have come into use to distinguish two classes of detectors. "Detect to warn" detectors are those that can provide warning in a sufficiently timely manner that significant exposures to agent are prevented. "Detect to treat" is reserved for detectors that do not provide warning in time to prevent exposures. The term "detect to treat" conveys the idea that, with knowledge of the attack, exposed troops can be treated; however, as we have noted above, not all biological agents have treatments and even some of those that do have treatments that are quite demanding. For example, treatment for botulinum toxin requires intravenous medication and sometimes respirator support. This level of treatment would not be available to the large number of potential casualties that might be caused by an attack with this agent. People who become ill would become essentially permanent casualties, even if not fatalities. Therefore, while "detect to treat" sounds benign, it may really signal that whole unit will need to be replaced in the near future. While this may be useful to know from a planning perspective, if replacements are not available, the real utility of "detect to warn" may be minimal.

WHAT TYPES OF BIOLOGICAL DETECTORS ARE CURRENTLY AVAILABLE?

There are two general categories of biological detectors. The first are generally called point detectors. These interrogate the atmosphere in their immediate vicinity, often by collecting a sample of air and processing it for indicators of biological agent. Examples of point detectors that have been fielded are the Biological Integrated Detection System (BIDS), which has been deployed with the 310th Chemical Company, and the Portal Shield detection system, which has been set up at several locations in CINCPAC and CINCCENT areas of responsibility.

The second type of sensor is the standoff sensor, which attempts to detect biological agent at a distance. Unlike chemical detectors, there are no passive technologies that are effective at identifying biological agent at a distance, or at least none has been identified so far. All standoff technologies rely on stimulating the aerosol cloud with some form of energy, and examining the energy return. The only standoff system to be deployed is the XM-94 infrared lidar-based system, intended for mounting in Blackhawk helicopters to search for long-line-source releases.

HOW DO POINT DETECTORS WORK? WHAT CAN THEY DO AND NOT DO?

In general, point detectors comprise three components. The first is a trigger that monitors the atmosphere for indicators of an attack. The objective of the trigger is not to provide warning, but to activate other portions of the system. Triggers, in theory at least, promote conservation of consumables, such as fluids and items used for identification, and thereby reduce the costs expended on these materials and relieve the burden on personnel who must service the detectors. Triggers can utilize components in each detector based on several detectors' outputs. There are other triggering cues as well, such as warning of an imminent attack.

The second component is sampling. Because point detectors are taking in air and, presumably, agent particles, they are well-suited to create samples, which usually involve dissolving the ingested particles in a solution of some type, although devices that prepare dry samples have been proposed. The samples serve two purposes—to support the third activity of point detectors—identification—and to provide suspect agent for further analysis and as evidence that there has been an attack.

The third component provides identification of the agent. This is often referred to as "presumptive identification," reserving the term "confirmatory identification" for a more rigorous laboratory analyses of the sample collected. Current detectors use antibody tickets, but other identification technologies such as polymerase chain reaction and mass spectroscopy have been proposed.

The main limitation of point detectors is that they must be in the aerosol cloud to work. This means, in general, that substantial numbers of point detectors must be used when an area must be protected. It also means that mobile forces must take their point detectors with them. Current point detectors tend to be large and have substantial power requirements. The BIDS is permanently mounted on a vehicle; Portal Shield is generally permanently emplaced.

HOW DO STANDOFF DETECTORS WORK? WHAT CAN THEY DO AND NOT DO?

Standoff detectors inject some form of energy into the aerosol cloud and examine the returns. Current standoff detectors and most standoff detector prototypes use light to stimulate the cloud. The XM-94 uses infrared light and displays the backscatter, which is collected in a telescope, on a screen, so that a trained operator can look for the characteristics of a line source. Several proposed detectors use ultraviolet light in

frequencies that cause fluorescence in chemicals associated with biological processes and evaluate all returned energy with an algorithm designed to distinguish biological material from non-biological matter. Some approaches attempt to distinguish biological agent from other, naturally occurring, biological aerosols such as pollen and mold spores. Because ultraviolet light is quickly absorbed by the atmosphere, some technologies use infrared light as a trigger, scanning with it until a suspect return is seen and then sending ultraviolet light in the direction of the suspect return.

The lidar or lidars and the telescope are usually joined into a single unit. These systems tend be large and require some sort of vehicle to move around. The system scans until it recognizes something in the atmosphere that its operator or software determines is likely to be a biological agent cloud.

The obvious strength of standoff detectors is that they can detect agent at a distance. If they are sensitive enough, and the distance is great enough, it is easier for standoff detectors versus point detectors to provide real warning, i.e., to prevent exposures, unless point detectors can be placed upwind of the protected area. For various reasons (see below), this may not be practical. Hence, standoff systems are often looked to for providing "detect to warn" capability.

Standoff detectors, because they can scan in different directions and altitudes to provide solid angular coverage, also have the potential for mapping out the agent aerosol cloud in three dimensions. One should be cautious about this claim however, since aerosol clouds tend to "thin out" in concentration near their edges, so that any standoff detector will miss some portion cloud near its edges. Hence, there might be hazardous conditions beyond what is mapped by the detector.

The limitations of standoff detectors are primarily their power requirements and size. Because of their sophisticated optics and the equipment needed to scan the system and to process the returns, they also tend to be expensive. Additionally, they are constrained by line-of-sight, which, in many areas of the world, limits their range to only a few kilometers for typical vehicle or surface mountings, independent of their sensitivities.

WHAT IS AN ACPLA? WHAT DOES IT MEASURE?

ACPLA stands for "agent containing particle per liter of air" and is typically used to specify detector sensitivities, as in "sensor X must be able to detect 25 ACPLA." However, as a measure of sensitivity, ACPLA leaves much to be desired. A "particle"

comprises some number of biological agent organisms (or a mass of toxin) along with various fillers and other material necessary to create an effective aerosol. But larger particles contain more agent, and the effect of given amount of agent in a particle varies with the type of agent used. Thus, specifying ACPLA is meaningless unless we know the particle size or distribution of sizes, and the agent we are talking about.

For example, let us assume that a three-micron particle contains 20 infective organisms of any bacterial agent. Simply scaling on a volume basis, a ten-micron particle will contain almost 40 times as many infective organisms, or about 800 particles. The agent anthrax requires on the order of 10,000 organisms for an infective dose, whereas brucellosis requires only 10 to 100 organisms. Thus an infective dose of brucellosis requires only a single three- or ten-micron particle, while an infective dose of anthrax requires 500 three-micron particles, but only about 12 ten-micron particles. While this discussion ignores a lot of important factors, such as the ratio of live to dead organisms in the particles and the differences in particle retention in the respiratory system as a function of particle size, it should be clear that a particular ACPLA sensitivity tells us little about the level of protection that a detector contributes to.

A final note regarding sensitivity. Dead infective organisms can retain those proteins and chemicals in forms that, although the organisms can no longer cause disease, they can be recognized, or even identified, as potential biological agents. Thus, in analyses, care must be taken to distinguish between the agent-containing-particles that result in positive detector results and agent-containing-particles that cause disease.

HOW IS SENSITIVITY OF DETECTORS MEASURED?

For point detectors, sensitivity is often given in terms of ACPLA. This is somewhat misleading in that an ACPLA-only specification is an instantaneous specification, leading to the assumption that if the aerosol exceeds the detector's ACPLA sensitivity for any period of time, however short, the detector will detect the agent. In fact, since most point detectors concentrate the aerosol for some period, a more correct specification would be in terms of aerosol concentration times time. However, since many aerosol clouds vary slowly with time around their peak, an instantaneous characterization of sensitivity may not be unreasonable.

For standoff detectors, sensitivity is a function of range because of the dispersal of energy on the way from the detector to the aerosol and back from the aerosol to the detector. Hence, standoff detectors are characterized by a sensitivity-range curve that specifies what the sensitivity is at ranges varying from the minimal detection range out to

some maximum. The detectable concentration increases with range, but not necessarily linearly. Specifying standoff detector sensitivity by a single ACPLA value at a single range is not sufficient to characterize the detector, since standoff detectors may have an opportunity to detect an aerosol at a number of different ranges (although the aerosol will be different at each of those ranges as the aerosol disperses). Moreover, different standoff detectors have different sensitivity-range curves, even if they agree at a given range.

WHAT FACTORS AFFECT SENSITIVITY?

Although sensitivity is often stated independent of other factors, a detector's performance is often affected by environmental variables. Point detectors may be affected by the amount of naturally occurring or manmade aerosols and vapors in the environment, and this environmental background can be quite high in many places of the world.

Standoff sensors are affected by atmospheric visibility, contributors to which include environmental background as well as water vapor, and by whether or not it is day or night, since detecting the relatively small energy returns from aerosol clouds is more difficult in sunlight.

For any type of detector, there is usually a relationship between sensitivity and false positive rate. In general, the higher the sensitivity, the higher the false alarm rate. Many detectors have adjustments that allow one to change the sensitivity in order to control the frequency of false alarms.

IS THIS THE BEST WAY TO SPECIFY SENSOR PERFORMANCE?

As we have noted above, he most serious drawbacks of specifying sensitivity using ACPLA are that 1) different particle sizes contain different amounts of agent, and 2) different agents have different levels of infectivity. Hence specifying performance in terms of ACPLA is difficult to relate to the operational goals for which one depends on sensors.

For specifying sensitivity requirements, it would be better to relate a detector's performance to the lethality of the threat. For a given agent (and assumed particle size distribution), sensitivity should be specified in terms of the number of (or fraction of) LD50s the detector could detect. This would relate performance directly to force protection. Even this forces us to make some assumptions regarding, for instance, the particle size distribution of the aerosol, the number of infective organisms per particle volume, and so forth. Nevertheless, relating detector sensitivity to the seriousness of the

threat provides operators with a clearer insight into how to respond to a detection (or non-detection in the presence of other indicators). An even better approach would be to characterize the way the detectors would be used and the level of force protection—i.e. no more than XX% of personnel exposed to YY level of agent for a relevant set of agents. Although some effort is needed to translate this type of specification into technical performance parameters, it is much easier for operators to specify the level of protection they require than it is for them to grapple with technical abstractions such as ACPLA.

ARE CURRENT DETECTORS SENSITIVE ENOUGH?

Existing detectors are likely to detect high concentration events, such as might result from attack with ballistic missiles or with artillery, even if the attack is at some distance (perhaps tens of kilometers) upwind from the detectors. Low concentration attacks, however, especially with agents that are highly infective or toxic, may not be detected, even though concentrations of a few ACPLA may be adequate to induce illness in large numbers of persons. Because low concentration attacks, which are typical of special operations or terrorist attacks, are the most likely to *not* have collateral signatures, such as those that might be seen by theater ballistic missile defenses or apparent explosions of munitions, it is most important that biological sensors be able to detect these kinds of attacks. If they are to do so, analysis has shown that improved sensitivity is required. For some agents—those that produce disease with only a few infective organisms—detector sensitivities well below single ACPLA levels will be needed to provide detection of attack. Achieving these levels of sensitivity is possible through several means. Both powerful concentration of aerosols (although that has power, weight, and size implications) and very sensitive detection technology can help biological detectors reach those levels.

WHAT ABOUT TIME TO DETECT?

As noted previously, detectors do not reduce exposures unless their time to respond is very short. However, since the time necessary for humans to receive an infective dose varies with the concentration of agent, it is important that very short detection times be associated with high concentrations. Longer detection times are allowable for lower concentrations as long as disease-causing levels of exposure can be prevented. If reducing exposures is not the objective, detection time is not critical, but should be short enough to provide indication that an attack has occurred before symptoms

appear so that treatment, if available, can begin. In this case, detection time shorter than several hours is probably adequate.

WHAT IS THE RELATIONSHIP BETWEEN SENSITIVITY AND FALSE ALARMS?

As with many types of detectors, biological detectors can experience false positives. If warnings are issued on the basis of these positives, unnecessary mission degradation can occur. Repeated false positives can lead to the detectors being ignored. Hence, operationally acceptable false positive rates are critical for biological detectors. For some detectors, false positive rates can be adjusted, but lower false positive rates generally mean lower sensitivity for a given technology (this is not true across technologies). Complicating this problem is the use of detectors in networks or in multiples. Doing this can increase the number of false positives. If false positives are randomly generated internally to the detectors, then the overall false positive rate will be approximately the single detector false positive rate times the number of detectors. If false positives are due to some environmental factor, then the system false positive rate might be closer to the single detector rate. We know very little about the impact of the environment on false positives at present. When evaluating detectors, it is important to combine technology parameters with concepts of employment that keep system false alarm rates within operational acceptable limits (and determining those limits is, in itself, a substantial endeavor). That will, in effect, determine the sensitivity of the detector system, and it is that sensitivity that has to be considered in assessing the effectiveness of the detector, rather than some single-detector sensitivity.

ARE BIOLOGICAL DETECTORS PRONE TO FALSE ALARMS?

The different technologies used in biological sensors have different false positive rates. These false positives don't become false alarms until a decision is made on the basis of the false positive. In general, the more specific the technology to specific agents, the lower the false positive rate. Therefore, technologies that look only at particles in the atmosphere will tend to have high false positive rates, while those that attempt to identify specific agents will have lower false positive rates. It is important to remember, however, that when large numbers of detectors are fielded, then the overall system false positive rate will be a function of the individual false positive rate. If false positives randomly occur, then the overall false positive rate will be the sum of the false positive rates of all the detectors. If false positives are caused by some environmental factor, then false positives among sensors will be correlated and the overall false positive rate will be

lower. As the false positive rate increases, the false alarm rate, the rate at which unnecessary actions are taken, will generally increase as well.

WHAT CAUSES FALSE ALARMS?

For different technologies, false positives will be caused by different phenomena. For technologies that assess only particles in the atmosphere, any increase in particles that resembles what might be seen in a biological attack could trigger a false positive. For antibody recognition technologies, false positives could come from materials that trigger antibody reactions or from the process by which antibody reactions are read. Hence, each technology that is proposed for biological detection must be evaluated on its own for its propensity to register false positives in the operational environment. Frequently, these technologies are tested in laboratories or at pristine test ranges that have very different environmental characteristics from where the detectors will actually be deployed.

WHAT DO WE KNOW ABOUT THE ENVIRONMENT WHERE BIOLOGICAL DETECTORS MAY BE EMPLOYED?

Very little. We tend to learn about the characteristics of the operational environment once detectors are fielded at particular locations, but even then, collected data are not always evaluated and analyzed for correlations with false positives. Moreover, the data collected by one detector may tell us little about the performance of a different technology. Data collected by a single device might not be able to illuminate the performance of a system of devices if the spatial positioning of the devices is important. The message here is that data collection in realistic operational environments and configurations should be part of the development, test, and evaluation process for any new biological detector.

FOR STANDOFF SENSORS, HOW MUCH RANGE IS REQUIRED?

One's immediate reaction to this question is "as much as possible," so that one sees requirements for detecting agent at low concentrations at tens of kilometers. Operationally, however, it is better to detect agent at the last possible moment that exposure can be prevented, allowing for time to make a decision to mask, for getting the word out, and for forces to prepare themselves. Knowing that there is agent at significantly greater distances—agent that may be diverted by changing winds—has not been shown to be operationally useful and, indeed, can be counterproductive if unnecessary protective actions are taken. Moreover, line of sight considerations limit visibility in many terrains to only a few kilometers. Hence, striving for a capability that

cannot be utilized in the field is a waste of money and effort. At the same time, the range of a standoff detector determines how much of a unit's frontage the detector can protect. Since standoff detectors tend to be expensive and fairly large, one wants as much coverage as possible from each detector in order to minimize the number needed. But this coverage is also often constrained by terrain effects as well as by the deployment of forces on the battlefield. Add to this the complication noted earlier, that detectable concentration and range are related—one cannot specify one without the other—and it is clear that the issue of range is inseparable from sensitivity, deployment location, basis of issue, threat, reaction time, and numerous other factors. Therefore, there is no hard and fast rule regarding how much range is enough. It should also be clear that a range "requirement" also has no meaning without the context describing how the detector is to be employed and what is expected of it. It would be better to set requirements in terms of operational characteristics (such as: provide the ability to prevent exposures to at least 95 percent of brigade personnel using four or fewer standoff sensors from such and such range of attacks).

ARE BIOLOGICAL DETECTORS ALWAYS NECESSARY?

As with everything, biological detectors have a cost. They require energy to run, sometimes have components that must be consumed for the detector to function, and divert manpower from other duties. As with any sensor, there is the possibility of false alarms, which can adversely affect Optempo if sufficiently frequent. Hence, thought must be given to the circumstances in which forces find themselves before automatically assuming that biological detectors are required. If there is little threat of the use of biological agents, biological detectors may not be needed. If the threat comes only from weapons for which there are other detectors, and protective measures are taken when those weapons are detected, it may be that only a limited sampling capability is required to confirm that a biological agent has occurred. If, however, there is risk of covert attack by special operations forces, terrorists, or transnational agents, using means that have no particularly obvious signatures, then only biological detectors can provide warning or evidence of an attack.

If forces are protected against biological agents through medical means, and that protection is sufficiently broad so as to protect against the possible range of agents that might be faced, then it is also not necessary to have biological detectors, unless it is necessary to prove that biological attacks have occurred. Providing that level of medical protection against a spectrum of agents is not currently feasible, however.

CAN BIOLOGICAL DETECTORS BE USED TO IDENTIFY HAZARD AREAS?

First, let us be clear on what "hazard area" means. As we have noted, in most cases biological agents do not create a static contaminated area in the same way that persistent chemicals do. Rather, the hazard area created by biological aerosols follows the movement of the aerosol until degradation of the agent or dispersion reduces the concentration of infective or toxic material below acceptable thresholds. Because hazards can continue to exist for considerable distances downwind from the release, hazard areas can extend for considerable distances beyond the detectors. Estimating where the agent goes depends on knowing the properties of the agent (which we cannot know until we analyze a sample of it) and on being able to predict the course of the winds, which is also a challenging problem. Moreover, to predict where agent will go, we need to know where it is at some time. We generally do not know this either. Even knowing where the agent was released does not tell us about the properties of the release, such as how far the agent was initially projected into the atmosphere during the functioning of the weapon. Having a series of detector readings also does not tell us the extent of the agent at any given time, unless we have a capability to map agent over a fine spatial grid at low concentrations. Standoff detectors do not have the sensitivity for this and point detectors are not spaced closely enough to do this. Hence, one should not expect precise estimates of biological hazard areas from biological detectors—the basic inputs are not available to even the most sophisticated prediction software. Nevertheless, it should be possible to do better than the gross hazard areas predicted by ATP-45 methodologies. As of yet, however, no one has demonstrated the use of detector information to provide reliable hazard area predictions that provide an acceptable degree of safety.

CAN BIOLOGICAL DETECTORS BE USED TO IDENTIFY THE END OF THE HAZARD PERIOD?

For the same reasons that detectors cannot be used to specify hazard areas, they also currently cannot indicate when biological hazards have passed. Both issues of sensitivity and distribution of sensors apply. Negative readings on sensors should be taken to mean only that the hazard has dropped below the detector sensitivity threshold or is out of range of the detectors.

HOW CAN YOU DETERMINE WHEN TO UNMASK?

Since detectors do not give definitive indication that no agent is present; they cannot be used to determine precisely when to unmask. Certainly, no unmasking should

occur while positive detections are being returned; however, once negative returns are obtained from all relevant sensors, there may still be hazardous material present, although in concentrations below the sensitivity threshold of the detectors. The hazard will continue to diminish, however, because of environmental degradation of the agent and because the wind will blow it away. Once sensors fail to register agent, the only recourse to ensure that it is safe to unmask is to wait for some period of time before unmasking. As far as we know, there has been no detailed exploration into how long this should be under various conditions. Under low or variable wind conditions, it may be necessary to wait a considerable time—hours perhaps—to ensure the agent is safely gone. If significant deposits of agent have occurred, for instance from munitions that detonated on site, there may also be the risk of re-aerosolization from people or vehicles moving through the area, or even from strong winds. Care must be taken to identify the location of such deposits and to decontaminate those areas. This hazard can linger long beyond the primary aerosol hazard.

HOW MANY BIOLOGICAL DETECTORS ARE NECESSARY TO PROTECT A UNIT OR SITE?

The key factors in determining the number of detectors needed to provide coverage are the nature of the threat and the sensitivity of the detectors in the local environment. If the threat is believed to be limited to extended line sources, then only a few sensors are needed. If small, covert point sources are part of the threat, sensors will have to be distributed throughout the base to catch the small clouds generated by these attacks. Sensitivity factors in because aerosol clouds are most concentrated near their centers, hence, highly sensitive detectors can be somewhat more dispersed than less sensitive detectors. There is a lower limit on sensitivity, however. If the detectors are not sensitive enough to detect the maximum concentration in the aerosol cloud, their spacing will be irrelevant. Another factor that may enter into the determination of how many detectors are required is the question of how many detections are required before an alarm is generated. In order to minimize false alarms, it is sometimes desirable to require two positive readings (on different detectors) before an order to assume protective posture or to take medical action is issued. This requires that detector density be such that two or more sensors are likely to fall within aerosol clouds, somewhat increasing the number of sensors required.

A constraint that often must be considered as well is the level of support needed by the detectors. On fixed sites, power, environmentally controlled storage of

consumables, and personnel to service sensors may not be a problem. For ground units, this infrastructure may not be available, so that the number of detectors ends up being determined by what can be supported rather than by estimates of what is needed to provide a given level of coverage. Even on fixed sites, however, the manpower available to service and operate the sensors may place a limit on how many sensors can be deployed.

WHAT DOES NETWORKING BIOLOGICAL DETECTORS MEAN?

The term "networking" can cover a number of concepts, from detectors that are linked by communications lines to a single command post to detectors whose outputs are combined and processed as a single data stream for purposes of increasing sensitivity or reducing false alarms. It is important to remember, however, that even detectors that simply report to a central location also undergo data fusion, in the sense that the operator will mentally correlate the outputs of the detectors to determine a course of action. Wherever decisions are taken to react to the outputs of detectors, those detectors should be considered to be networked. Only where a detector is used by itself can it be considered not networked.

ON WHAT PLATFORMS CAN BIOLOGICAL DETECTORS BE MOUNTED?

Existing biological detectors have been stationary mounted (Portal Shield), mounted in helicopters (XM-94 LIDAR), and placed on mobile platforms (BIDS) but operate only when the platforms are not moving. How the detectors should be mounted depends on how the detector is to be used.

For fixed sites, fixed mounting is reasonable. Indeed, given the uncertainties of when or from which direction attacks will come, there is little advantage in expending the manpower to continually reposition sensors in response to wind changes or tactical situations. Repositioning also complicates the process of data fusion, if it is part of the detection process.

For mobile units, the detectors must remain with the units. To avoid time-consuming set-up and strike operations, it is desirable to mount the detectors on vehicles that will accompany the units. If those units are combat units, then the vehicle platforms should be combat vehicles. Of course, the detectors should not interfere with the primary mission of the vehicles, so the detectors should be able to function on the move at typical vehicles speeds and maneuvers and should operate in such a way that the crew is not diverted from their operational roles.

Ships also require biological detectors, since they are vulnerable to attack with area dispersion weapons. Standoff detectors could provide early warning provided they could operate in the naval environment.

Aircraft could benefit from point detectors to provide protection of the crew and passengers, but dedicating an aircraft to biological detection might not be a cost-effective use of that platform. Because most aircraft cruise at several kilometers, sensitive stand-off detectors would be needed. The XM-94 LIDAR detector, as noted above, was intended to be mounted on a helicopter. While the detector worked well against the class of sources it was designed to detect, the need for a helicopter—a scarce theater asset—limited its practicality.

It is often suggested that biological detectors be placed on UAVs that can either conduct a form of airborne surveillance or that can be launched to interrogate a suspicious cloud. There are a number of considerations that might constrain such use. First, if point detectors are the payload, the UAVs will have to fly close to the ground to ensure that it flies into the agent cloud. Flying UAVs at low altitudes is a challenging operation, posing a potential threat to forces and possibly interfering with other activities. Standoff sensors could be flown at higher altitudes, but they tend to require large power supplies and are heavy, mandating the use of large (and expensive) UAVs.

Conducting surveillance with UAVs will require multiple platforms to ensure that an aerosol cloud is detected in a timely manner. Given the need for backup platforms to keep one in the air, a substantial investment in UAV operations will be needed to perform surveillance. Adding in the support requirements (fuel, maintenance, etc.) means that this kind of operation will require additional force structure and manpower to effect.

A responsive use of UAVs would require fewer platforms. The challenge here is to vector the UAV to where the aerosol cloud is as it moves with the winds. Because it is undesirable to launch a responsive UAV without good confidence that a biological agent is present, it will be essentially necessary to have a standoff biological detector to identify the agent cloud. Although the UAV could take samples of the cloud, which the standoff detector could not, the protection function of the UAV-mounted detector is redundant with that of the standoff detector, reducing the military value added of the responsive UAV approach.

An expendable platform for detectors has also been discussed from time to time. The concept of employment is that many detectors would be scattered around a unit's area of operations and left there as the unit moved on. There is no technology cheap or

simple enough to support that kind of operation. Moreover, such a use would mandate a detector that could not be exploited if collected by opposing forces. Knowing the sensitivity of the detectors as well as the agents the detector was capable of responding to would be important intelligence for an enemy. Some internal components of existing sensors are considered classified for that reason.

IS THERE SUCH A THING AS BIOLOGICAL RECONNAISSANCE?

Chemical reconnaissance involves searching for and marking contaminated areas. These makes sense for low volatility agents that can create a persistent hazard on the surface. The small size of particles in biological aerosols, however, causes the aerosol to act more or less as a gas. Hence, there is very little deposition on the ground. Moreover, agent that is on the ground is not a problem unless it is re-aerosolized and becomes respirable. Detecting low levels of agent on the ground is therefore not only difficult, but generally unnecessary. Of course, if a warhead fails to function, hits the ground and breaks open, and there is a pile of powdery material in the vicinity, that should be treated as a suspected hazard, sampled, and marked.

WHAT IS THE STATE OF THE ART FOR SIMULATING DETECTORS?

Because it is difficult to duplicate the conditions of a real attack in the laboratory or even in field tests, a capability for simulating biological detectors in their operational configurations is vital to understanding how best to use detectors, and to measuring their contribution to military effectiveness. Although simulation is a valuable tool in this regard, there are important limitations to the current state of the art of detector simulation. Perhaps foremost among these is our limited understanding of the environment in which detectors must function. Not only are there naturally occurring biological and non-biological aerosols that can mimic some of the characteristics of actual attacks, there also are a variety of chemicals and biological materials to be found in the military environment that can interfere with the operations of detectors. These factors, which appear to behave randomly in many respects, contribute to false positives. Our lack of understanding of these phenomena means that our simulations provide little information regarding false positives to be experienced in the field.

Because the movement of the aerosol cloud is important, especially as it affects the correlation of information from multiple sensors, the ability to model the movement of the aerosol cloud is critical. Here, too, we face simulation limitations. While highly complex codes exist to track aerosol movement over terrain and through cultural features,

and can reproduce detailed micrometeorological effects, these codes are generally too burdensome to employ in typical detector analyses. The two most commonly used aerosol transport and diffusion programs—VLSTRACK and HPAC—perform reasonably well in most analytical situations, but do not always provide similar results given similar input conditions. They both have the advantage that they run reasonably quickly, allowing sensitivities to be explored. Neither, however, models micrometeorology in great detail, nor are the effects of cultural features, such as buildings and terrain details, generally represented (even where the models have the capability to incorporate detail, such as terrain, most users do not exercise these capabilities).

A third limitation is that detector models frequently do not model in detail the information components of the detectors themselves. For example, a standoff detector might be modeled through an implementation of the lidar equation, but the display that an operator might see, or the decision algorithm that a detector system might use, often are not modeled. One reason for this is that these elements of the detection process often are not complete at the time of the greatest analytical interest, where concerns for military utility, basis of issue, and detector placement are being examined.

DO FIELD TESTS PROVIDE USEFUL INFORMATION?

Like simulations, field tests also have limitations. Current regulations prevent the use of actual agent and, although some simulants appear to be reasonable facsimiles of actual agent, not all agents have realistic simulants. Further, releases rarely reproduce munitions operations realistically. Releasing a few kilograms of laboratory-grade simulant using air guns, as is often done at field tests, is much different from releasing hundreds of kilograms of impure agent explosively from a warhead.

It is also difficult to control, or even measure, the concentration of agent when it is released. Hence, the concentration that a detector encounters in a field test is not often typical of what it might see in an actual attack. Finally, the environment around the test grids, which is typically barren desert remote from civilization, is not typical of the environment where actual detector deployments occur. In particular, natural and manmade interferents that might be encountered on an airbase or in a ground unit are not present in field tests. The interferents that are typically used, chemical smokes and burning materials, may affect detector technologies differently from the hydrocarbons, dust, and other substances that might be found on the battlefield or in built-up areas where fixed sites are often located. As a result of these environmental differences, the

sensitivities and false positive rates displayed by detectors in field tests may be much different from what is achieved by detectors in the real world.

WHAT CONSIDERATIONS GO INTO COST-EFFECTIVENESS TRADEOFFS?

Like all military systems, biological detectors should be evaluated in terms of both their contribution to force protection and the costs involved in developing, procuring, and operating them. Because detectors based on different technologies can have very different performance parameters and substantially different costs, detector systems need to be compared on a cost-effectiveness basis. This is rarely done. Full system costs, covering the life cycle of a militarized, deployable sensor system, are almost never presented. More commonly, the procurement costs for developmental units are considered, and operating and support costs ignored. One possible reason for this is that these expenses often fall into different accounts, with R&D, procurement, and operating costs being the responsibilities of different organizations. Nevertheless, it is the overall costs of detectors that have to be considered to reflect the overall impact on the defense budget.

The contribution of the detectors to force protection—the effectiveness side of the equation—must also be as broad as possible. Simple measures of performance, such as sensitivity or false positive rate, do not, by themselves, tell much regarding system performance. Realistic threats, realistic operational situations, and realistic measures on the ability of the detectors to permit forces to accomplish their military objectives must all be combined in the analysis.

HOW SHOULD REQUIREMENTS FOR BIOLOGICAL DETECTORS BE DETERMINED?

In a similar manner, the requirements for biological detectors have to be determined not by listing a series of simple performance measures, such as sensitivity, size, power requirements, etc., but from an analysis of how the detectors will be used, and what performance is needed to keep military units functioning in the light of expected threats. In general, this is likely to be an iterative process, requiring assessments of multiple detector architectures to determine the best combination of features to provide robust force protection across the uncertain range of threats.

It is also important to remember that detectors, by themselves, do not protect forces. They must be considered in the context of available medical and protective procedures, information that might characterize biological attacks that might come

through other means, and the actions that information might provoke (such as donning protective gear).

FINAL OBSERVATIONS

Biological detectors are a key component of an overall defense against biological weapons, which have the potential to undermine US military capabilities through their ability to cause mass casualties. That they can be developed and delivered covertly makes them even more insidious. Understanding the nature of the biological threat and how biological detectors work are specialized areas of knowledge, which require expertise in meteorological phenomena, physiology, medicine, antibody reactions, lidar physics, and other diverse areas of science. Determining the military utility of detectors requires all of the above, as well as an understanding of how military forces operate and an ability to combine all of this in an operational analysis.